DTU Library

Studies on the effects of ionizing radiation for extending the storage lives of onions

Skou, Jens-Peder

Publication date:
1971

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Skou, J-P. (1971). *Studies on the effects of ionizing radiation for extending the storage lives of onions*. Risø National Laboratory. Denmark. Forskningscenter Risoe. Risoe-R No. 238

Risö Report No. 238

Danish Atomic Energy Commission

Research Establishment Risö

Studies on the Effects of Ionizing Radiation for Extending the Storage Lives of Onions

by J. P. Skou

February, 1971

Sales distributors: Jul. Gjellerup, 87, Sölvgade, DK-1307 Copenhagen K, Denmark

Available on exchange from: Library, Danish Atomic Energy Commission, Risö, DK-4000 Roskilde, Denmark

February, 1971

Risö Report No. 238

Studies on the Effects of Ionizing Radiation for Extending the Storage Lives of Onions

by

J. P. Skou

ERRATUM

Page 24, last line of the text to figure 8: read *x 500 instead of x 1000*

February, 1971 Risö Report No. 238

Studies on the Effects of Ionizing Radiation for Extending the Storage Lives of Onions

by

J. P. Skou

The Danish Atomic Energy Commission
Research Establishment Risö
Agricultural Research Department

Abstract

Experiments with ionizing radiation for extending the storage lives of onions are described and compared with the available literature on the subject. The aim was to form a general picture of the effects of ionizing radiation applied to onions on the basis of the multitudinous environmental and physiological conditions influencing the results.

All that contributes to optimal growth, uniform maturation, and good storage conditions will improve the results. Only first-class market onions should be used for irradiation as even apparently negligible deviation from that category will increase the rot during storage. It was found very important to use strains of cultivars with a specially good storability. The best results were obtained with irradiation shortly after lifting when the onions are in the deepest state of rest. At that time only 6-12 krads were necessary to inhibit, but not to prevent, the onions from sprouting. At the above conditions the effect on the incidence of rot will be small, but all deviations from them may result in an increase in both sprouting and rot. Doses above the optimal for sprout inhibition causes an increase in storage rot and may promote a transitory, relatively high sprouting rate within 1-2 months after the application. Small bulbs sprout faster than larger ones. Discoloration of the growth centre of irradiated onions may often occur, but with great variation between strains of cultivars and from one bulb to another. The cause has not been elucidated, but some explanations are given. Generally the discoloration should not make the onions objectionable for most kinds of use. The total loss by respiration and transpiration in the whole storage period was greatest in the non-irradiated, but in the first months of storage, until the sprouting accelerates, the loss was greatest in the irradiated onions. The culinary value was practically unchanged.

Additional keywords: Sprout inhibition, storage rot, Botrytis allii, dormancy, radiation botany, physiology, cultivar.

ISBN 87 550 0073 8

CONTENTS

Page

1. INTRODUCTION

On account of sprouting and storage rot onion growers have serious problems with storage of the bulbs, and therefore they are always looking for methods or remedies to reduce these factors. Various chemicals have been used or are in use - to the author's knowledge to a small extent only - for that purpose in different countries, but they are of limited value because of too little effect, or because they may be dangerous to man.

This is the basic reason for making experiments with irradiation for extending the storage lives of onions. Numerous investigations have been carried out throughout the world since Brownell et al. (1954, see Mullins and Burr 1961) and Dallyn, Sawyer and Sparrow (1955) presented the first reports on sprout inhibition in onions by irradiation. This literature is reviewed below to the extent to which it has been possible for the author to trace it. Part of the literature appears only as short notes or reports, and some of the results described were based on too small amounts of bulbs to be regarded as conclusive. Only in connection with other experiments are they, maybe, of some value. From this literature review one arrives at the conclusion that it is not enough just to take some onions, irradiate them and look at the results, because the variation in storability between strains of cultivars is influenced not only by their heritable properties, but also by the physiological, environmental, and growing conditions. This makes it a complex task to get an unambigous picture of the effects of the irradiation and constitutes the basis for making the irradiation experiments presented below.

2. LITERATURE REVIEW

Throughout the world the main part of the experiments have been carried out with onions (Allium cepa L.), but the existing results with garlic (A. sativum L.) and shallots (A. ascalonicum L.) indicate that they fall within the variation in the results with different strains of cultivars of onions. Strain (kind of plant material) and cultivar (proprie dicta variety, smallest unit of the plant system) are used in sensu Wanscher (1964, 1971). Where not otherwise indicated onions were the subject of the investigation. Doses are given in rads or krads throughout the paper without any change in original figures differently denominated.

2.1. Effects on Sprouting and Physiology

2.1.1. Changes in Growth Behaviour, Tissues, and Metabolism of Nucleic Acids

Transplanting of onions treated with 0-5 krads of X-rays resulted in a decreasing number of bulbs sprouting in the field (Campos, Generoso and Capinpin 1960). Srb (1965a) agreed by stating that a dose of 1 krad of X-rays was too close to the lethal limit for transplanting with a fairly good result. Metlitskii et al. (1964) found that a dose as small as 200 rads inhibited development of flower-bearing shoots, and further that normal cell division was lacking after application of 10 krads. They claim that instead the cells hypertrophied so the growth that occurred was mainly a cell extension.

Already at a dose of 100 rads of X-rays it was possible for Srb (1965a) to measure an increase in the permeability of the tissues of onions, and he ascertained that 1000 rads caused nearly the same effect as did 5 or 25 krads. This effect could be observed immediately after irradiation, and was partly reversible, partly irreversible (Hluckovský and Srb 1963, Srb 1964, 1965a). There can be no doubt that such changes in permeability will cause severe changes in the physiology and whole behaviour of the tissues including an increased susceptibility to microbial attacks. Cf. below, and for analogous effects in carrots and potatoes cf. e.g. Skou (1963, 1966, 1971) and Skou and Henriksen (1964).

Korableva and Metlitskii (1963) and Metlitskii et al. (1964) proved that it is the irradiation-disturbed metabolism of the nucleic acids which leads to a suppression of the sprouting ability. Three to ten krads stopped the synthesis of nucleic acids at storage, and higher doses resulted in a direct decomposition. At sprouting the content of nucleic acids increased 4-5 fold in the non-irradiated onions, while there was only a weak increase after 100, and a loss in nucleic acids after 300 krads. In onions the irradiation (0-300 krads) caused a drop in both RNA and DNA, most pronounced in primordia and in stems and roots especially when irradiation was applied during the state of intense growth. In garlic the content of RNA in the meristems decreased both during storage and with the dose of irradiation (0-500 krads), while it was almost unchanged in the parenchyma. The decrease of DNA was less.

For comparison with other plants see e.g. the references in Skou (1966).

The effects of irradiation on the genetic constitution are beyond the scope of the present paper.

2.1.2. Type of Radiation and Doses Necessary for Sprout Inhibition

The earliest reports on sprout inhibition in onions by ionizing radiation gave greatly varying figures for the doses needed. There are many reasons for that, several of which are solved to day. First of all it is necessary to use a type of rays with energy enough to penetrate to the growth centre of the bulbs. Thus Dallyn and Sawyer (1959a) got no reduction in sprouting after use of 128 krads 2 MeV fast electrons, but only a weak inhibition of the root-forming ability, and after 2 krads there was even a tendency to stimulation of the sprouting. In other experiments they found increasing inhibition from 2 to 64 krads applied to the root-end, but not when applied to the top-end. With γ-rays no sprouting occurred after 4-8 krads. van Kooy and Langerak (1961) used 1 MeV fast electrons without any effect after doses up to 750 krads, apart from a tendency to increased sprouting at the greatest doses.

It must also be disadvantageous to use sources with too low a dose rate, e.g. in an outdoor γ-field, not only because of the uncontrolled environmental conditions, but also because the difficulties in comparing the results on non-irradiated samples and samples irradiated to different doses for varying periods of time. Dallyn, Sawyer and Sparrow (1955) used such an outdoor irradiation plant, but for 2 days only, while Patil (1965/66) placed his onions in a γ-field for 1-32 days before storage at constant temperature and humidity, see remarks to his results below.

Early it was found that irradiation at different times after harvest (maturity) gave dissimilar results. According to Mullins and Burr (1961) already Brownell et al. (1954) found sprouting at all doses up to 39 krads. Similar results were obtained by Truelsen (1960) after irradiation 1 and 4 months after harvest. At the same time a transitory stimulation of sprouting in onions but not in shallots, was observed immediately after irradiation. Using several different doses Mullins and Burr (1961) also observed such a transitory stimulation after application of 50 and 250 krads 118 days after harvest. Applied 76 days after harvest only the latter dose caused that effect. None of the doses used completely prevented the onions from sprouting, but by irradiation 12 days after harvest only weak sprouting was observed after doses as low as 2-6 krads. Neither Korableva and Metlitskii (1963) nor Metlitskii et al. (1964) got a prevention from sprouting with 100 krads to onions or with 500 krads to an early ripening strain of a cultivar of garlic, but as little as 10 krads has a good inhibitive effect on sprouting in onions. Patil's (1965/66) results remind us of the stimulating effect in spite of the fact that they are difficult to compare with others. Using doses up to 60 krads he found the strongest sprout-inhibiting effect with 10-20 krads. Brunelet and Vidal (1960) did not find any effect after irradiation of onions and garlic in April, while they observed increasing sprout inhibition with increasing doses after irradiation of onions in February, even though distinct sprouting was observed after 18 krads. Two krads could inhibit sprouting in onions and garlic at still earlier application, while shallots required 12.5 krads for sprout inhibition in August after harvest in July. With irradiation in July and August Watanabe and Tozaki (1967) found 100% inhibition in garlic after 3 krads, while 4 krads had no effect at all when applied in November. Complete prevention from sprouting could be obtained with 15 krads until 86 days after harvest, but this dose was not enough when used 114 days after harvest (Ojima et al. 1963).

Several authors agree on the excellent effect of 5-15 krads used shortly after harvest, and further that the effect of these doses is weak or nil when used at a later date (Brunelet and Vidal 1960, Mullins and Burr 1961, McQueen 1965); some talk about complete prevention (Sawyer and Dallyn 1956, Dallyn and Sawyer 1959a, b, Lewis and Mathur 1963, Mathur 1963 (garlic), Ojima et al. 1963, Kahan and Padova 1966 (garlic), Mumtaz et al. 1970), others found complete prevention or only slight sprouting at even smaller doses (Ogata et al. 1959, according to Patil 1965/66, Hori, Kawasaki and Kitoh 1965, McQueen 1965, Solanas and Darder 1968, Messiaen, Pereau-Leroy and Leroux 1969, garlic), and finally there is a group of authors who simply found a reasonably good reduction in the sprouting with 5-20 krads (Blinc 1959, Meshitsuka et al. 1963, Kahan et al. 1966, Zidan 1967, Kahan and Temkin-Gorodeiski 1968, Dharkar 1969, Umeda, Takano and Sato 1970). I do not think it is necessary to attach very much importance to these differences in the way of expression, but maybe there exist strains of cultivars in which, under certain conditions, it is possible to obtain full prevention from sprouting by using those relatively low doses of radiation.

In the greater part of the experiments only the external sprouting has been investigated, but it is evident that considerable internal sprouting must occur before the outer one may be observed, and it is obvious that it would be preferable to stop development of the internal sprouting (see e.g. Dallyn and Sawyer 1959a, b, Brunelet and Vidal 1960, McQueen 1965). On the other hand some internal sprouting usually does not impair the market value of the onions.

2.1.3. Rest and Dormancy*

One thing is clear from the preceding section, that is: the sooner after harvest (maturity) irradiation was used, the better the results and the lower the doses needed to inhibit sprouting. Brunelet and Vidal (1960) and Metlitskii et al. (1964) mention that they got the strongest sprout inhibition when irradiation was applied while the onions were in deep dormancy or in the period of rest, but they do not give any explanation or definition. Investigations of that matter have shown that the onions are in a state of rest for some time - up to 8 weeks - after harvest. In that period the onions are unable to sprout unless special agents are used. Later on the rest is less deep, and the onions pass into a state of dormancy in which they may sprout when placed in good conditions (Jones 1921, Boswell 1924a, b, Mann and Lewis 1957). The intensities of rest and dormancy differ, not only from one strain to another (Messiaen, Pereau-Leroy and Leroux 1969, garlic), but also from early to later ripening onions of the same strain (Boswell 1924b).

When these facts are compared with the results of irradiation, it is clear that when the onions are in the state of rest it is possible to get a good effect with small doses, while by irradiation in the period of dormancy or when the sprouting has already initiated, higher doses are required, but these increase the injury and involve more or less unpredictable results.

Only Dallyn and Sawyer (1959b) got more sprouting by irradiation of the Southport White Globe immediately after lifting than when irradiation was applied 26 days later. Perhaps it is possible to come too close to the time of maturity with the use of irradiation, i. e. before the onions pass into the deep rest.

Both the roots and the top are in the state of rest after harvest (see Mann and Lewis 1957), but as in carrots (Skou 1966) it is easier to inhibit sprouting of the roots than of the top (Dallyn and Sawyer 1959a, Patil 1965/66).

2.1.4. Importance of Strains of Cultivars, and of the Bulb Size

The comparatively few investigations with garlic (Allium sativum L.) and shallots (A. ascalonicum L.) (Brunelet and Vidal 1960, Truelsen 1960, Mathur 1963, Metlitskii et al. 1964, Kahan and Padova 1966) do not show differences from onions (A. cepa L.) as to the effect of irradiation, as the variations observed between strains of cultivars (sensu Wanscher 1964, 1971) of onions were quite as great (Dallyn and Sawyer 1959a, b, Nuttall, Lyall and McQueen 1961, McQueen 1965, Kahan and Temkin-Gorodeiski (survey of the variation within Israeli cultivars) 1968, Umeda, Takano and

* For endogenous and ectogenous influenced dormancy it is in the present paper used the terms rest and dormancy respectively, as did Boswell (1924a), and Mann and Lewis (1957) and their sources, but opposite to what might be the common use of to-day (see Vegis 1965).

Sato 1970), not only as regards the effect of radiation, but to storability as a whole (cf. e.g. Sørensen 1941). Also between strains of garlic a clear difference was observed (Metlitskii et al. 1964). In spite of the few strains compared in each experiment it seems reasonable to presume that the observed differences are due to the genetic constitution of the strains of cultivars, affected by the growing conditions and the treatment at and after harvest (cf. Boswell 1924 b, Meshitsuka et al. 1963, Kepka 1969).

Results were also influenced by the bulb size as small bulbs sprout faster than larger ones of the same strain (Dallyn, Sawyer and Sparrow 1955, Sawyer and Dallyn 1956, Nuttall, Lyall and McQueen 1961). Zidan (1967) reaches the opposite result, but his material was too small to be conclusive, and Metlitskii et al. (1964) too, found a similar indication.

2.1.5. Pretreatments and Storage Conditions

Conditions affecting the storability of onions will certainly also affect the results of the radiation treatments. These conditions comprise the pretreatments, i. e. the bulbs should be healthy and well dried, preferably artificially (cf. Knoblauch 1959 (shallots), Brunelet and Vidal 1960, Kepka 1969, Shirokov 1969), as well as the growing conditions, i. e. uniform growth and ripening should be secured (cf. Boswell 1924a,b), and the storage, where the temperature is very important, as shown by Boswell (1924b), Mann and Lewis (1957), and Knoblauch (1967, shallots).

In the irradiation experiments storage at low temperatures, i. e. close to zero centigrades, may shorten the state of rest, while storage at 13 - 17°C gives a more vigorous sprouting than higher and lower temperatures (Lewis and Mathur 1963, Meshitsuka et al. 1963, Dharkar 1969). Exactly the temperature has been subject to the most extreme variations from one author to another, and thus it has contributed greatly to the differences in the results. The extremes of storage temperatures used were -2°C (Knoblauch 1967, shallots) and 35°C (Lewis and Mathur 1963). Several authors have kept the onions at ambient temperatures.

Also the relative humidity (r.h.) varied greatly, i. e. from 30-40% r.h. (Dallyn, Sawyer and Sparrow 1955) to close to 100% r.h. which especially affect the susceptibility to storage rot. The best moisture content should be 80-95% r.h. (Kurki 1969). It is worth mentioning in this connection that Meshitsuka et al. (1962) and Srb (1965b) found more sprouting in packaged onions than in onions lying free, very likely owing to the higher moisture content in the bags. This is in agreement with what has been found in carrots (Skou 1966).

2. 2. Storage Rot

Several authors talk about storage rot as "... sprouting and decay ...", "... decay ..." or "... spoiled ..." more or less in connection with sprouting, and thus the real importance of that matter is hidden. Others did not find differences, or they observed a decrease in storage rot with increasing doses of radiation - even at relatively small doses (Lewis and Mathur 1963, Mathur 1963, McQueen 1965, Messiaen, Pereau-Leroy and Leroux 1969, garlic, Mumtaz et al. 1970). The significant decrease in storage rot with increasing doses found by van Kooy and Langerak (1961) is probably due to the high doses (1 MeV fast electrons) given towards the neck leaving the rest of the bulb protected. Dallyn and Sawyer (1959a) found a more or less pronounced tendency to increased storage rot after use of fast electrons as well as after γ-rays. Mullins and Burr (1961) note that onions treated with 250 krads "spoiled" very rapidly, and Metlitskii et al. (1964) found increasing storage rot with increasing doses and a very severe rot after 500 krads in both onions and garlic.

Nuttall, Lyall and McQueen (1961) observed less rot in the irradiated than in the non-irradiated onions in the first part of the storage period, later the storage rot was most pronounced in the irradiated ones. At the same time they observed - like Dallyn and Sawyer (1959a) - a great difference between strains of cultivars as to storage rot, further that small bulbs were less susceptible to rot than were the larger ones. This applies to both irradiated and non-irradiated ones. Patil's (1965/66) experiments, certainly not comparable with others, in many cases showed severe internal rot in the irradiated bulbs owing to a greatly injured growth centre or even injured sprouts. With the preceding section in mind, the differences in the importance of the storage rot are not surprising.

Metlitskii et al. (1964) mention attacks by Botrytis allii Munn, and Staden (1966) alleged that this fungus could be destroyed by irradiation without damage to the onions. Besides these, only Messiaen, Pereau-Leroy and Leroux (1969, garlic) and Mumtaz et al. (1970) mention the causal organisms which were Penicillium spp. and Aspergillus spp. respectively.

Part of the spoilage or decay is probably physiological in nature as for instance the spoiled spongy onions of Mullins and Burr (1961) who stored the onions at about 50% r.h.

2. 3. Respiration and Transpiration Loss

Several statements about the weight loss at storage of irradiated onions refer only to the total loss at the end of the experiments without details of the development during storage (see Ojima et al. 1963, Srb 1965b, Kahan et al. 1966, Dharkar 1969, Mumtaz et al. 1970). During storage of onions from August till the end of December when practically no sprouting occurred, the difference in weight loss between irradiated and non-irradiated ones was insignificant with a tendency to more loss in the irradiated bulbs of Early Yellow Globe, and during storage of onions from August till October at conditions allowing sprouting, the loss was greatest in the sprouted non-irradiated onions (Dallyn and Sawyer 1959a). In the papers of Lewis and Mathur (1963) and Mathur (1963, garlic) it is possible to follow the development in loss during storage. When onions were stored at ambient temperatures (21-35°C) and 57-95% r.h. without sprouting for 5-6 months, there was merely a tendency to greater loss in the non-irradiated onions, but at storage at 11-12°C and 85-90% r.h. the advantage of the irradiated onions was very obvious because of 100% sprouting in the control within 4 months against none in the irradiated, in garlic above 20% and none respectively. This was the main cause of the great difference in weight loss (60.9% and 16.6% for onions and 24.0% and 14.8% for garlic respectively). Patil (1965/66) recorded the greatest loss in the non-irradiated, but within the irradiated the loss increased with the dose.

2.4. Discoloration of the Growth Centre

Dallyn and Sawyer (1959a, b) showed, using 1 and 2 MeV fast electrons towards the root-end of onions, that the growth centre became brownish discoloured to the extent of 75% of the bulbs, while they did not observe any discoloration when the same doses were applied towards the top-end, probably because the electrons did not penetrate to the growth centre. After irradiation with 8-12 krads of γ-rays they got more discoloration than after 16 krads. They stated that the reason was injuring or killing of the meristematic tissue, and that the variation from one bulb to another might be connected with the size of the growth centre or internal sprout at the time of irradiation. They also observed differences between the strains of cultivars used.

Brunelet and Vidal (1960) found the discoloration closely related to the growing point which possibly died after some growth when small doses were applied, while no growth at all was initiated after greater doses. Contrary to this Nuttall, Lyall and McQueen (1961), Hori, Kawasaki and Kitoh (1965), and Kahan and Temkin-Gorodeiski (1968) reached the conclusion that the discoloration more or less increases with the doses.

Brunelet and Vidal (1960) stated that discoloration is caused by enzymatic activity rather than by microorganisms, while Nuttall, Lyall and McQueen (1961) were of the opinion that the brownish discoloration might be an early state of storage rot.

Patil (1965/66), who applied the radiation at ambient temperatures in a γ-field for 1-32 days during which some growth occurred, got very intense discoloration in the irradiated bulbs. He stated the cause to be death of the tissues in the great growing centres extending upwards close to the neck, and that the onions were then attacked by microorganisms through the neck. This is an extreme case. Usually the discoloration constitutes only a very limited part of the whole bulb, and it is therefore not objectionable to most purposes (Dallyn and Sawyer 1959b). Zidan (1967) agreed in that and added that the dry dead growing centre would anyhow be cut away together with the root disc.

Different storage conditions caused broad variations in the degree of discoloration in the cultivar Autumn Spice in which discoloration of the heart also occurred in the non-irradiated bulbs (Nuttall, Lyall and McQueen 1961). In other experiments McQueen (1965) did not find serious discolorations after 3-4 or 8-12 krads, and in these cases there was no discoloration in the control of Autumn Spice. This made him conclude that the discoloration is due to pre-existing conditions as a tendency which may be intensified by irradiation. If this is the correct answer, the cause is analogous to what has been observed as to the internal discoloration in potatoes (cf. Truelsen 1964, Skou 1967).

Sprout inhibiting doses gave practically no discoloration in garlic (Kahan and Padova 1966).

2.5. Culinary Value and Wholesomeness

The outer appearance seems unaffected by the irradiation apart from a faster drying-up of the outer scales (Blinc 1959, Lewis and Mathur 1963). When cooked the irradiated onions may get a lighter colour than the non-irradiated (Dallyn and Sawyer 1959b), and when sliced and dried the irradiated onions had the best colour (Zidan 1967).

Taste and smell are rather improved by irradiation. Some authors found a milder (i.e. less pungent) and a slightly sweeter taste of irradiated onions (Dallyn and Sawyer 1959b, Nuttall, Lyall and McQueen 1961, Lewis and Mathur 1963, McQueen 1965), whereas other authors have not found differences worth mentioning either in raw or in cooked condition (Truelsen 1960, Mathur (garlic) 1963).

Both by sensory evaluation and by chemical determination the volatile reducing substances that are responsible for the pungency increased with the dose without any adverse effect or off-flavour to the onions after 2-10 krads (Mumtaz et al. 1970). This is - maybe - connected with enzyme activity; at least the enzymes and their substrates were more easily brought together when the permeability increased, see above. In this connection it is worth mentioning that the activity of alliin-lyase (the enzyme decomposing alliin and alliin-analogous substances to allicin (or related substances), pyruvic acid, and ammonia, allicin and its allies being responsible for the characteristic taste and smell of onions and garlic, cf. Hegnauer 1963) was unchanged after doses up to 64 krads, but the enzyme became less soluble (Watanabe and Tozaki 1967).

The contents of reducing and non-reducing carbohydrates were unchanged at sprout-inhibiting doses (Dallyn and Sawyer 1959b, Lewis and Mathur 1963, Metlitskii et al. 1964, McQueen 1965). This holds for vitamin C, too (Lewis and Mathur 1963, McQueen 1965).

Extensive experiments for testing of the wholesomeness of irradiated onions are unknown to the author, but McQueen (1965) mentions that no detrimental effects were observed in animals as a result of a diet containing onions irradiated with doses up to 100 krads.

3. EXPERIMENTAL

3.1. Material and Methods

Two series of experiments with irradiation of onions were performed during the years 1965-1969. One series was with different doses to one strain (sensu Wanscher 1964, 1971) of the cultivar Rijnsburger of the species Allium cepa L. That is for the years in question (strain-mark in brackets):

1965/66 Rijnsburger (Stensballe S 65)
1966/67 Rijnsburger (A. H.)
1967/68 Rijnsburger (A. H. 1001)
1968/69 Rijnsburger (Stensballe S 65)

The other series was performed with one dose to several strains of cultivars (cf. tables 2 and 3). All these strains of cultivars were grown together in the same field, treated, harvested, and handled at the same time which is considered of importance for studying differences.

The onions were harvested in the beginning of October every year and field-dried the first three years of the experiments (1965/66 - 1967/68), while those used for the 1968/69 experiments were transported to Risö immediately after lifting and placed for 8 days on a drying plant blowing cold, dry air through the nylon baskets, and they were then sorted and irradiated.

All onions used were first-class market onions unsorted to size. The average size may be seen from table 1 which gives detailed data of the outline of the experiments. The onions were grown at Stevns. In the 1965/66 experiment the onions were stored at the grower's among other onions. From the other experiments some onions were stored in a frost-free ventilated room at K. V. Andersen's factory for onion products at Varpelev, Stevns, others at 5°C and 50-60% r.h. at Risö.

The road distance to Risö is about 50 km.

The samples were irradiated in the indoor ^{60}Co irradiation plant at Risö at the times and to the doses indicated in table 1.

Few authors mention the methods of judgement used in the experiments. Mullins and Burr (1961) and Mumtaz et al. (1970) threw away all onions sorted out, and so did I with the aim of reducing spreading of diseases and limiting the sprout-accelerating ability of sprouting onions (cf. Ottosson 1969). It may be discussed to what degree this way of sorting makes the results different from those with onions in practical storage which remain untouched until removal for sale. Leaving the rotted onions in the samples may give more rot than occurs in practice, on the other hand throwing away the sprouted onions may lead to less sprouting than in practice. In spite of this, the author does not think the method used disturbs comparison with good practice.

This way of sorting may make the percentage of rotted onions somewhat misrepresented if a very high percentage of sprouting onions were sorted out at an earlier date.

The onions were judged once a month by weighing and sorting into first-class market onions, sprouted, and rotted ones. When a bulb had both sprouts and rot, it was placed according to what was most pronounced on it. As soon as leaf sprouts penetrated the neck, the bulb was regarded as sprouted.

Results may be based both on weight and number. Based on weight the respiration and transpiration loss cannot be omitted as part of the results. These two factors are regarded as having the greatest influence on the bulbs sorted out. On the basis of number we were free of those disadvantages, but calculating on number alone does not make it possible to get an impression

Table 1

Outline of the experiments. Amounts, sizes and treatments of onions are given for the different experiments. All treatments but one were performed with 6 replications. Harvest in the beginning of October every year.

Year of experiment	Time of irradiation	Doses applied, krads	Place of storage	Total amount in		Amount per sample		Weight per onion, g
				kg	number	kg	number	
Experiments with different doses to one strain:								
1965/66	17th Dec.	0, 12, 50, 250 x)	Stevns	168.0	2536	8.0	121	66.2
1966/67	28th Oct.	0, 6, 12, 25	Stevns	192.0	1383	8.0	58	138.9
1967/68	1st-3rd Nov.	0, 6, 12, 25	Stevns	150.0	892	6.3	37	168.5
1967/68	1st-3rd Nov.	0, 6, 12, 25	Risö	160.1	967	6.7	40	166.7
1968/69	14th Oct.	0, 6, 12, 25	Stevns	218.0	1439	9.1	60	151.5
1968/69	14th Oct.	0, 6, 12, 25	Risö	226.9	1480	9.5	62	153.3
Experiments with strains of cultivars:								
1966/67	28th Oct.	0, 12	Stevns	432.0	4774	8.0	86	92.9
1967/68	1st-3rd Nov.	0, 12	Stevns	398.0	4735	6.0	72	84.1
Total				1945.0	18206	-	-	-

x) For 250 krads 3 replications only.

of how the weight loss was influenced by treatment and time. Figure 1 gives the results of the last experiment at Risö calculated in per cent after both methods. No fundamental difference may be seen, only the "weight curves" show a lower per cent of first-class onions than do the "number curves", see above. All results are therefore given by number, apart from those estimating weight and weight losses.

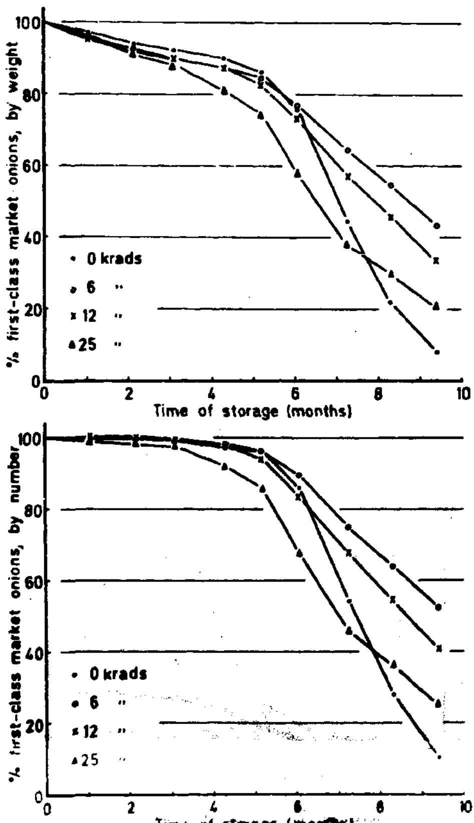

Fig. 1. Comparison between measurements by weight (top) and by number (bottom) of per cent of first-class market onions in the experiment at Risö [illegible]. Note that the main courses of the curves are the same.

3.2. Results of Experiments with Different Doses to a Single Strain of a Cultivar

The results were all based upon the material and doses outlined in table 1 for the different experiments during 1965-1969.

3.2.1. Sprouting

1965/66 Experiment. This preliminary experiment started exceptionally late (17 Dec.), cf. the literature review. The control had considerable sprouting after 3 months, while it took 4.5 months before onions irradiated with 12 krads reached that level. After application of 50 krads a hint of sprouting appeared already after one month, but the sprouting stopped and amounted to only about 2% after 4.5 months. No sprouting appeared after application of 250 krads.

1966/67 Experiment. In the non-irradiated onions sprouting accelerated rapidly after 4 months of storage and reached 85-90% within 7 months, see figure 2. In that same time sprouting after application of 6 and 12 krads reached only 15%. After application of 25 krads the sprouting was initiated already after 2 months, and after 3-4 months these onions still had more sprouts than the control, but the sprouting rate faded off to give only 25% sprouts after 7 months.

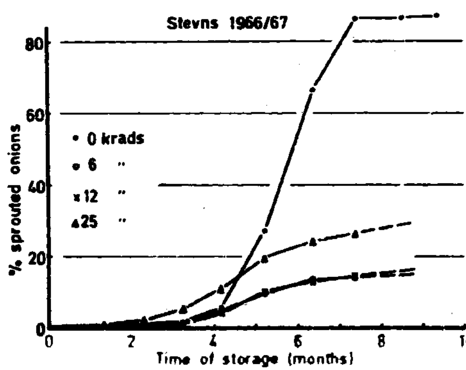

Fig. 2. Amount of sprouted onions in the 1966/67 experiment. Note the accelerating sprouting rate in the non-irradiated after about 4 months (approx. 1st March) of storage and that sprouting is first initiated in onions treated with 25 krads.

Already after one month of storage some root sprouts were found in the control samples, while no root sprouts at all occurred in the irradiated samples during the whole storage period.

1967/68 Experiments. Sprouting in the control was less than the preceding year, but the main course of the curves is the same for the Stevns-stored onions, i. e. earlier and more sprouts after 25 krads than after 6 and 12 krads, see figure 3 at top. In the Risö-stored onions the sprouting started about 2 months later, and the irradiated onions sprouted more than those of the Stevns-stored experiment. The strongest sprout inhibition occurred after 6 krads, and both after 12 and 25 krads the onions sprouted earlier and had more sprouts after 4-6 months than had the control, see figure 3 at bottom.

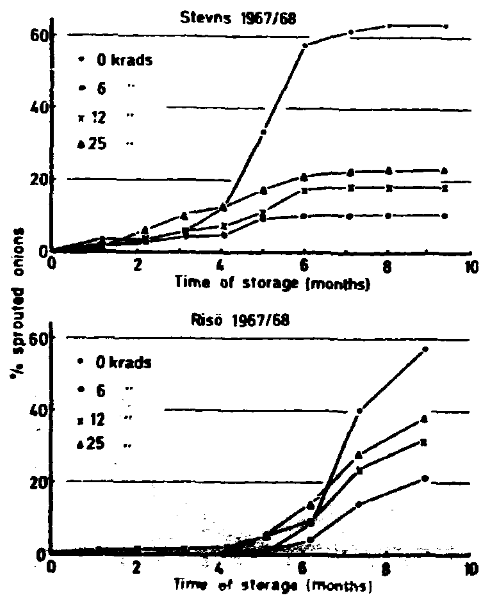

Fig. 3. Amount of sprouted onions in the 1967/68 experiments. Note that sprouting starts later at Risö than at Stevns, but there is more sprouting in the irradiated at Risö than at Stevns, and that sprouting is first initiated in onions treated with 25 krads (at Risö also with 12 krads).

1968/69 Experiments. Both the Stevns-stored and the Risö-stored onions started sprouting after 5.5-6 months of storage, see figure 4. The sprouting rate of the control was much higher at Stevns than at Risö, probably because of the constant 5°C at Risö. As the preceding year the irradiated onions sprouted somewhat more at Risö than at Stevns. At both places onions treated with 25 krads had more sprouts than those treated with 6 and

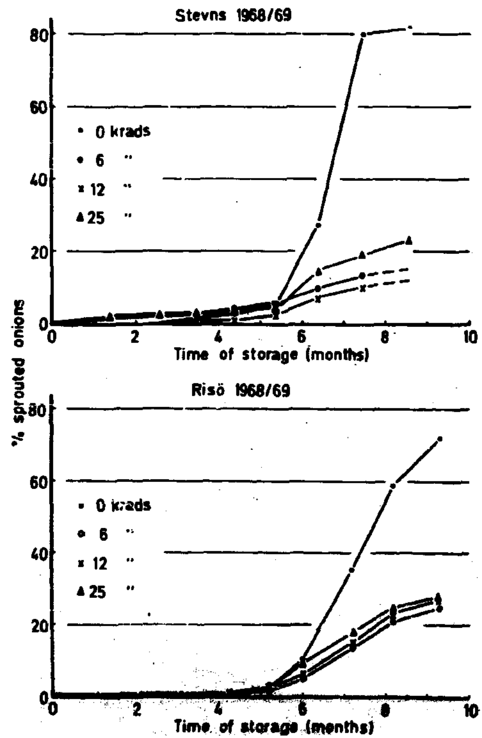

Fig. 4. Amount of sprouted onions in the 1968/69 experiments. Note the late initiation of sprouting, and that no transitory stimulating effect occurs with any of the doses used.

12 krads, but without an earlier initiation. This may be connected with the fast drying and the earlier treatment, certainly carried out when the onions were in the deepest state of rest (cf. literature review).

3.2.2. Storage Rot

1965/66 Experiment. In the control and in onions given 12 krads the storage rot amounted to 35% after 3 months and approx. 95% after 4.5 months, while those given 50 and 250 krads had 42% and 75% respectively after 3 months and 99% and 100% after 4.5 months. So the higher doses obviously made the onions very susceptible to storage rot.

1966/67 Experiment. In this experiment the storage rot was moderate, gradually ascending during the first 7 months of storage without differences between treatments, but at that time the rot started to increase rapidly in the irradiated samples, see figure 5. This is connected with the fact that it was impossible to keep out all the summer heat from the storage room. The extreme difference between irradiated and non-irradiated as to the amount of rotted onions is to a certain extent brought about by an earlier sorting out of the sprouted bulbs, cf. material and methods. The curve for the control is therefore somewhat misleading in the later part of the course and does not tell much about differences in susceptibility.

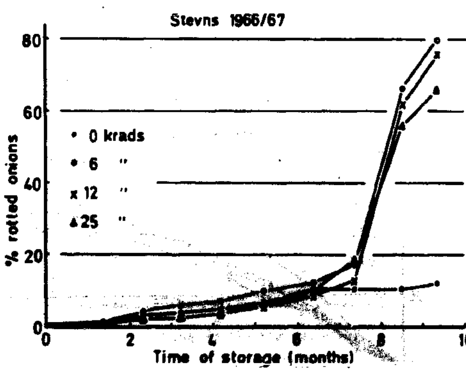

Fig. 5. Amount of rotted onions in the 1966/67 experiment. For explanation of the courses of the curves see the text.

1967/68 Experiments. That year the autumn was very rainy entailing serious difficulties for field-drying the onions, and into the bargain this gav an increased chance for infection and rot. The effect of these conditions is obvious from the results in spite of the fact that the experiments were commenced with apparently healthy bulbs only, see figure 6. In both experiments the storage rot developed seriously straight from initiation of storage and it was generally more severe at Stevns than at Risö, see figure 6. As a whole there was most rot in the irradiated samples throughout the experiments, even when the above-mentioned difficulties are taken into consideration.

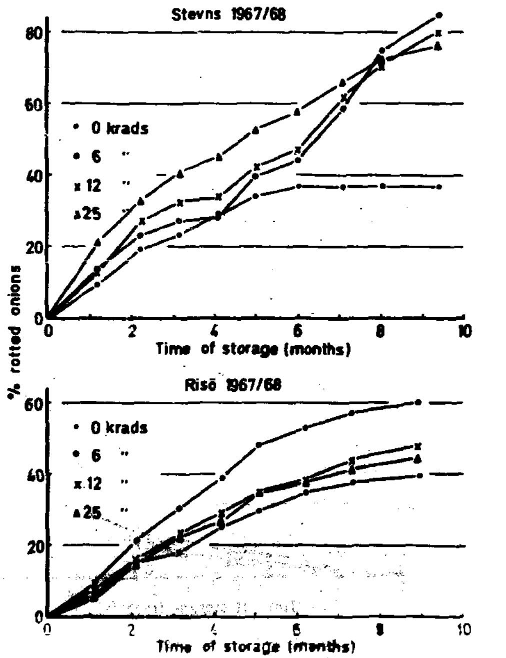

Fig. 6. Amount of rotted onions in the 1967/68 experiments. Note the high rate of rotting that year, and that the irradiated samples generally have more rot than the non-irradiated ones.

<u>1968/69 Experiments.</u> On the basis of the bad experience from the preceding year the onions were artificially dried immediately after lifting, cf. material and methods. The results of the Stevns-stored onions were similar to those from 1966/67, see figure 7 at top and compare with figure 5. In the Risö-stored onions there was practically no rot in the first 4 months, but from about that time the rot accelerated in all treatments and at a rate increasing with the doses, see figure 7 at bottom. The main part of this increase in rot does not seem to have been caused by microorganisms,

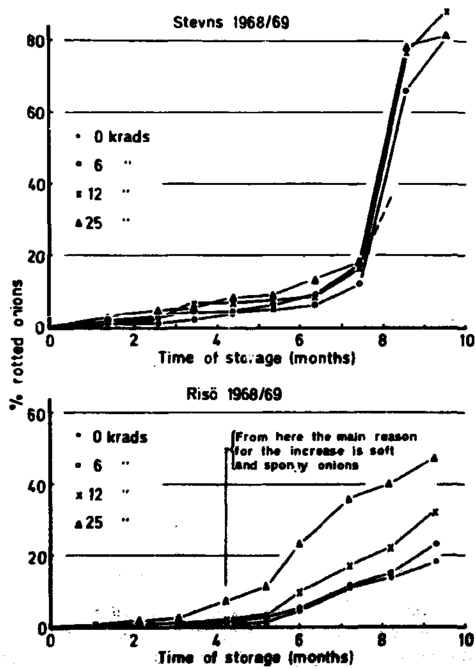

Fig. 7. Amount of rotted onions in the 1968/69 experiments. Note the rapid increase in rot after 7.5 months (approx. 1st June) at Stevns and compare with the text. No differences between doses can be seen. At Risö the courses of the curves are somewhat different, see the text for closer explanation.

but rather by physiological conditions. This kind of "decayed" onions also occurred at Stevns, but it was not enough to change the course of the curves In the Risö-stored onions only those treated with 25 krads had more rot than the Stevns-stored ones after 7 months. It is impossible to decide under what set of conditions the soft and spongy bulbs were induced. The low relative humidity (50-60%) and the more intensive drying have perhaps contributed, cf. Mullins and Burr (1961).

3.2.3. The Causal Organisms

Except for a few cases with Penicillium spp., the gray mold (Botrytis spp.) was the cause of nearly all the storage rot in all the experiments except for that stored at Risö 1968/69, cf. above. The main part of the gray mold was caused by Botrytis allii Munn (det. ex descr. in Hellmers 1943 and Hennebert 1963) including the small-spored "variety" (cf. Røed 1952, Hennebert 1963) of which an isolate is deposited at CBS, Baarn, The Netherlands, as accession no. CBS 260.71, see figure 8.

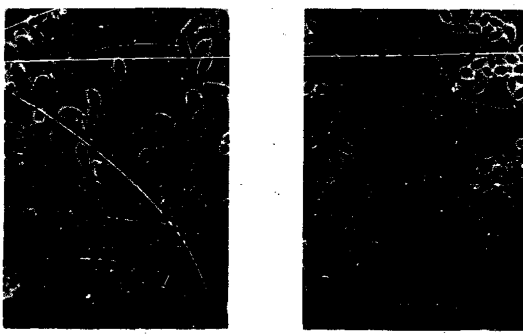

Fig. 8. Conidia of the gray mold fungus, Botrytis allii Munn. Left: a large-spored isolate, no. 28 (in average 11.0 x 5.1 μ, length/breadth 2.2) Right: a small-spored isolate, no. 798 (in average 6.8 x 4.0 μ, length/breadth 1.7). x 1000.

3.2.4. Respiration and Transpiration Loss

Figure 9 shows how the average bulb weight decreased during the storage period of the last experiment at Risö. Within the first 6 months the treatment did not cause any difference in the average bulb weight, but as the sprouting accelerated in the control samples, they lost much more in weight than did the irradiated ones.

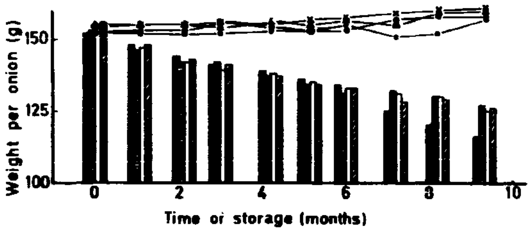

Fig. 9. Changes in the weight of onions during storage in the 1968/69 experiment at Risö. The 4 columns are from left to right: 0, 6, 12, and 25 krads. Symbols at the curves are as in the other figures. The columns show the actual weight during storage, and the curves show the calculated weight when compensating for the respiration and transpiration loss. Compare with figure 1.

As no sorting as to size of the bulbs was made, cf. material and methods, it should be recognized through a change in the average weight of the bulbs if the general storability (i.e. all onions minus the sprouted and rotted ones) was affected by the size, but at the same time, however, there will during storage be a loss through respiration and transpiration for which it is necessary to compensate if in this way we try to get an answer as to the importance of the bulb size. The curves above the columns in figure 9 give the calculated bulb size after compensation for the measured total weight loss up to any time during storage. If chiefly small onions have been sorted out, the compensation would make the curves rise which in fact they do, but we have to take into consideration that the bulbs with the most intense respiration and transpiration are the ones sorted out owing to sprouting and rot. Therefore the rise of the curves may be due to compensation on a relatively too great rest weight. Compare figure 9 with the two sets of curves in figure 1.

The weight losses in the Risö-stored and in the last of the Stevns-stored experiments are given in figures 10 and 11. If we take the figures period by period, we generally find the greatest loss in the irradiated samples during the first 2-3 months of storage; then the differences reduce to be without significance until sprouting sets in and brings the control far above the others if an intense rot does not occur at that same time as in the Stevns-stored onions, see figure 11 at top. The very small loss during the winter period at Stevns is due to a temperature close to 0°C. Based on the whole storage period the loss was greatest in the control.

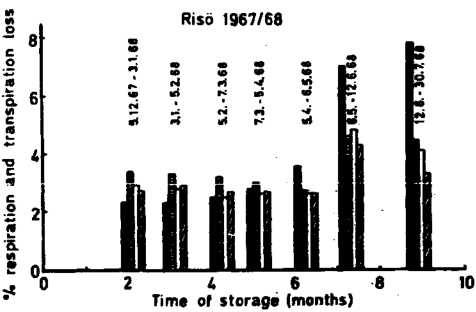

Fig. 10. Respiration and transpiration loss during storage in the 1967/68 experiment at Risö. The 4 columns are from left to right: 0, 6, 12, and 25 krads.

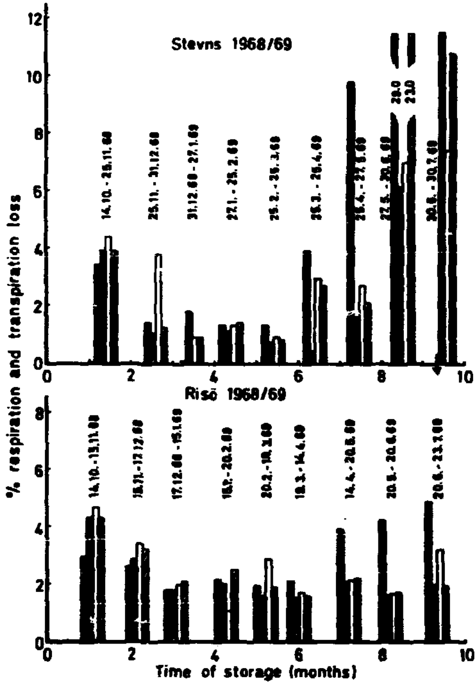

Fig. 11. Respiration and transpiration loss during storage in the 1968/69 experiments. The 4 columns are from left to right: 0, 6, 12, and 25 krads.

3.2.5. First-Class Market Onions During Storage

The first-class market onions comprise all onions minus the sprouted and rotted ones. Calculated in this way the difference between control and irradiated samples is less than it would be on the basis of weight in the last part of the storage time because of the greater respiration and transpiration loss in the control. The opposite is the case in the first part of the storage time, see above and material and methods.

After 4-5 months the difference in amounts of first-class market onions starts to be significant. Only in the 1965/66 experiment did sprouting and rot develop so rapidly that no marketable onions were left early in May.

1966/67 Experiment. Here the advantage of the irradiation is clear from April and onwards until the summer heat promotes the rot and brings the whole experiment to a sudden end, see figure 12. Six and twelve krads were significantly better than 25 krads.

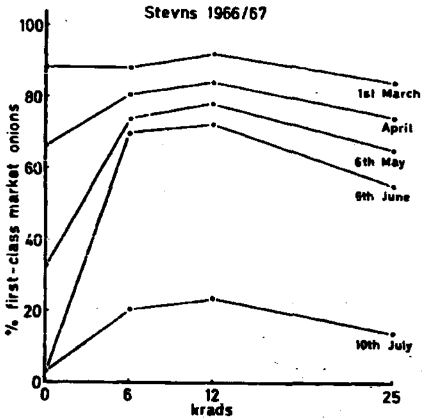

Fig. 12. Amount of first-class market onions in the later part of the storage period in the 1966/67 experiment after application of different doses.

1967/68 Experiments. The Stevns-stored onions gave almost the same picture as the preceding year, see figure 13, only the percentage of first-class market onions is lower because of the fast developing rot that year, see figure 13 at top. For the same reason the positive effect of the irradiation did not show until the middle of June in the Risö-stored onions, see figure 13 at bottom. Storing onions with a constitution like that of this year (see storage rot) was obviously best at Stevns probably because a low temperature during winter slows down the rate of rotting.

Six krads were better than 12 and 25 krads.

1968/69 Experiments. As in 1966/67 both experiments (Stevns and Risö) clearly show the advantages of irradiation, see figure 14 and compare with figure 12. The essential difference between the 2 localities is again the summer heat. Again 6 krads were better than 12 and 25 krads because of more sprouting and rot at the higher doses.

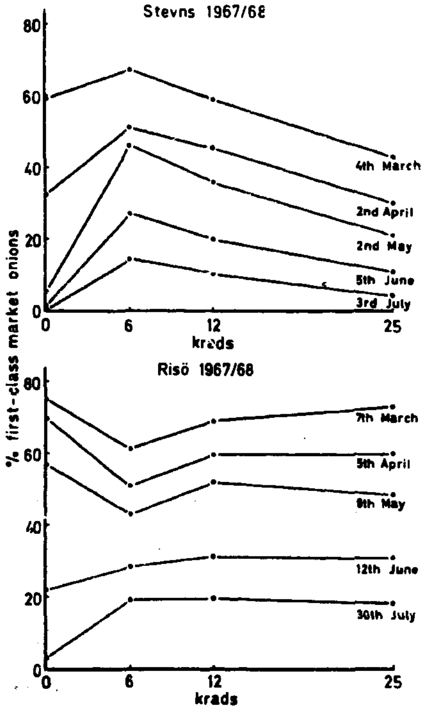

Fig. 13. Amount of first-class market onions in the later part of the storage period in the 1967/68 experiments after application of different doses. Note the difference between the 2 places of storage and compare with the text.

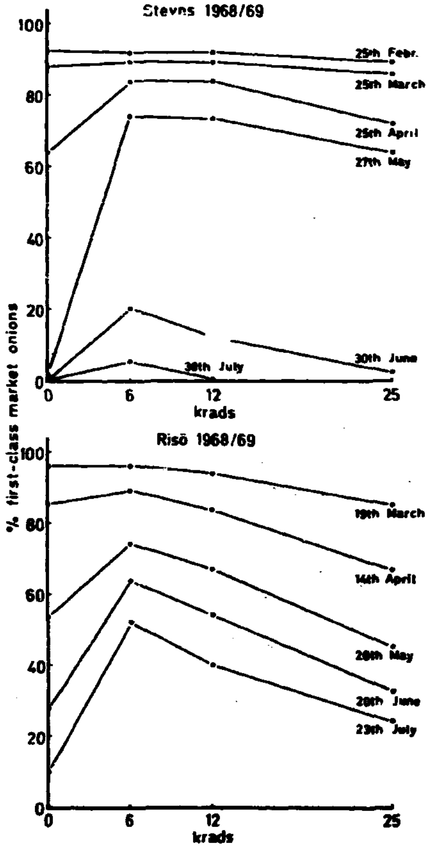

Fig. 14. Amount of first-class market onions in the later part of the storage period in the 1968/69 experiments after application of different doses. Note the great amount of marketable onions and compare with figures 1, 4, 7, and 11.

3.3. Results of Experiments with Strains of Cultivars

This second series deals with several strains of cultivars in which only the 12 krads were compared with non-irradiated. The greatest advantage of this comparison is the uniformity in growing conditions and handling etc., see material and methods.

3.3.1. Sprouting

In figure 15 the weakest and strongest sprouting irradiated strains are set up together with the irradiated and non-irradiated control and the average of all irradiated strains. In the 1966/67 experiment the curves had a shape that appeared "normal" as compared with the first experimental series, even though the extremes in sprouting ability of the irradiated strains are clearly different. In the 1967/68 experiment the shape of the curves for the irradiated strains was quite different. The main cause of this was most likely the great difficulties with the field-drying that autumn which apparently gave rise to greater or smaller shortening or cessation of the period of rest, resulting in a slighter inhibition or a directly stimulating effect on the sprouting by application of the radiation. Thus all irradiated samples had more sprouting than the non-irradiated control after one month of storage. This condition is exceedingly pronounced in the strongest sprouting strain with 27% against about 5% in the non-irradiated. The stimulating effect was only transitory as the sprouting rate faded off so that the total sprouting became greatest in the non-irradiated samples.

3.3.2. Storage Rot

As in the first experimental series the curve for the non-irradiated control is somewhat misleading in its later course because of an earlier sorting out of great amounts of sprouted bulbs, cf. also material and methods. In both years very pronounced differences between the strains as to the amount of storage rot were found, see figure 16. They were extreme after the wet autumn of 1967 when the most susceptible strain had above 70% rot after one month of storage, while the most tolerant strain had only about 15% rot or as much as the most susceptible strain the preceding year.

3.3.3. Storability of Strains of Cultivars

The amounts of sprouts and rot in the strains of cultivars naturally play a decisive role for the storability, and as they obviously vary independently, an interaction may arise. It is therefore necessary to take both conditions into consideration when determining the storability of a strain.

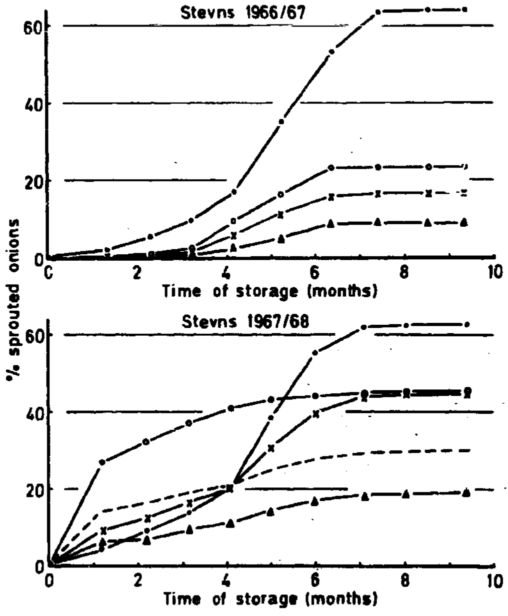

Fig. 15. Amount of sprouted onions during storage in the experiments with different strains of cultivars. Dots: non-irradiated control. Crosses: same strain irradiated with 12 krads. Open circles: the most sprouting strain (12 krads). Triangles: the least sprouting strain (12 krads). In the 1966/67 experiment (top) the average sprouting for 9 strains is very close to the irradiated control (the crosses). The dashed line gives the average of 11 irradiated strains in the 1937/68 experiment (bottom).

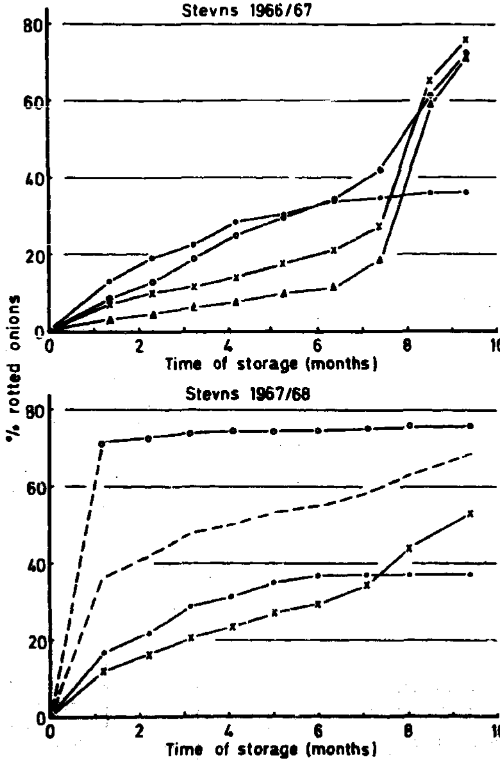

Fig. 16. Amount of rot during storage in the experiments with different strains of cultivars. Dots: non-irradiated control. Crosses: same strain irradiated with 12 krads. Open circles: the most rotting strain (12 krads). Triangles: the least rotting strain (12 krads). In the 1966/67 experiment (top) the average for 9 strains is very close to the irradiated control (the crosses). In the 1967/68 experiment the least rotting strain out of 11 is the irradiated control (the crosses). The dashed line gives the average of 11 strains in the 1967/68 experiment. Note the great differences within and between the years and compare with the text.

In table 2 the strains of cultivars from the 1966/67 experiment are put together, placed according to percentage of first-class market onions as judged on 6 June 1967. The strain Rijnsburger (A. H.) from the first experimental series of that same year and doses are inserted. It is very clear that storage rot is far the most important factor for placing the strains in the table. Further it is worth noting that the commonly grown strain, Rijnsburger (A. H.), is the one with the best storability, and that the differences between strains of that cultivar were very pronounced. The advantages of irradiation are obvious, even though there is only a non-irradiated control for two of the strains because of shortage in material.

Table 2

Storability of strains x) of some cultivars of onions (A. cepa) from experiments with storing at Stevns 1966/67. Figures from the test on 6th June, 1967. Highest and lowest amounts of sprouts and rot are underlined. Strains, Rijnsburger (A. H.), on dashed lines are transferred from first experimental series of the same year. Harvest in the beginning of October, irradiation 28th October.

No.	Cultivars with strain-mark in brackets	% sprouted onions	% rotted onions	% first-class market onions
	0 krads			
-	Rijnsburger (A. H.)	86.4	11.4	2.2 ± 0.8
-	Rijnsburger (Stensballe S 65)	64.0	34.1	1.9 ± 0.5
	12 krads			
-	Rijnsburger (A. H.)	14.8	13.3	71.9 ± 0.8
1	Hollandsk, halmgul	16.7	18.9	64.4 ± 2.4
2	Rijnsburger (E. L. D.)	11.7	24.5	63.8 ± 2.5
3	Rijnsburger (Tagenshus 240 O. E.)	23.4	19.5	57.1 ± 1.7
4	Rijnsburger (Stensballe S 65)	16.4	27.4	56.2 ± 5.8
5	Rijnsburger (153/66 Ø. F.)	8.7	35.2	52.1 ± 3.5
6	Rijnsburger (Tagenshus S 65)	20.1	26.0	51.9 ± 1.9
7	Zittauer (A. H.)	20.1	34.8	45.1 ± 3.8
8	Rijnsburger (Hunderup S 65)	19.8	42.0	38.2 ± 1.5

x) Sensu Wanscher 1964 and 1971.

The corresponding data for the 1967/68 experiment are given in table 3 for the judgements on the 2 April and 5 June. The 2 judgements are put in to get an impression of the development of sprouting and rot after the wet autumn, see above. Again the tolerance against storage rot had an overwhelming importance for placing the strains in the table. The 3 irradiated strains with the poorest storability did not have a greater amount of first-class market onions than the non-irradiated control. Rijnsburger (A. H. 1001)

Table 3

Storability of strains[x)] of some cultivars of onions (A. cepa) from experiments with storing at Stevns 1967/68. Figures from the tests on 2nd April and 5th June 1968. Highest and lowest amounts of sprouts and rot are underlined. Strains, Rijnsburger (A. H. 1001), on dashed lines are transferred from first experimental series of the same year. Harvest in the beginning of October, irradiation 1st - 3rd November.

Cultivars with strain-mark in brackets	% sprouted onions		% rotted onions		% first-class market onions	
	2nd April	5th June	2nd April	5th June	5th April	5th June
0 krads						
Rijnsburger (A. H. 1001)	33.6	61.6	34.1	36.7	32.3 ± 5.1	1.7 ± 1.2
Rijnsburger (Stensballe S 65)	38.5	62.0	34.9	37.1	26.6 ± 3.7	0.9 ± 0.4
12 krads						
Zittauer, gul kæmpe (Hunderup S 62)	14.5	18.4	44.6	50.5	40.9 ± 5.9	31.1 ± 5.1
Rijnsburger (Stensballe S 65)	31.3	44.1	26.9	34.2	41.8 ± 5.7	21.7 ± 6.0
Rijnsburger (A. H. 1001)	17.7	25.9	45.2	53.0	37.1 ± 5.8	21.1 ± 4.5
Rijnsburger (A. H. 1001)	11.4	18.1	42.7	62.1	45.9 ± 1.8	19.8 ± 4.9
Rijnsburger (Hunderup S 65)	20.7	23.0	60.7	63.7	18.6 ± 2.3	13.3 ± 1.7
Rijnsburger (F. D. B. 925)	24.7	29.0	51.1	57.5	23.8 ± 4.5	12.8 ± 2.3
Rijnsburger (Tagenshus 240 O. E.)	25.6	28.4	62.4	65.5	12.0 ± 2.9	6.1 ± 1.2
Perijka (Toftø S 65, 920)	32.6	33.2	59.7	61.6	7.7 ± 1.9	5.2 ± 1.2
Rijnsburger (Tagenshus S 65)	28.9	31.5	62.9	65.0	6.3 ± 1.4	3.5 ± 1.6
Brunsviger (1964 O. E.)	48.4	45.2	51.7	52.8	4.9 ± 1.8	2.0 ± 0.9
Zittauer (A. H.)	23.4	24.3	74.5	75.4	2.1 ± 1.4	0.3 ± 0.3

x) Sensu Wanscher 1964 and 1971.

from the first experimental series is inserted. Also this year the commonly grown strains ranged among the best, see above.

The importance of using strains with good storability can certainly not be made more clear than is shown in this table where out of the best of the irradiated strains - under the circumstances mentioned - there were 30% first-class market onions left on 5 June, while nothing was left from the poorest strain at that time.

3.3.4. Importance of Bulb Size

No special effect of the bulb size was detected with certainty in the first experimental series, but here in this series a close connection between the percentage of sprouting bulbs and the average weight of the bulbs was observed in the 1966/67 experiment, see figure 17 and compare with table 2.

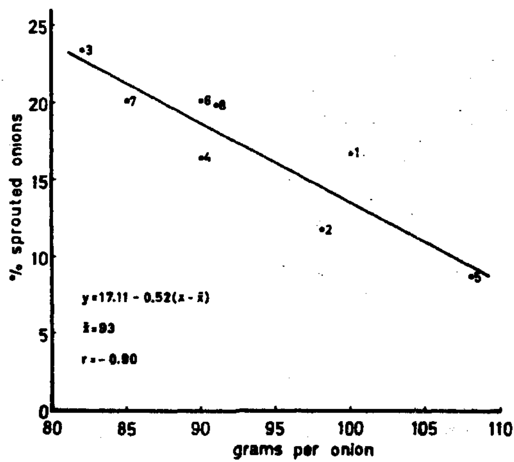

Fig. 17. The relation between sprouting and bulb size as found in the experiment with strains of cultivars in 1966/67. The numbering refers to the placing in table 2, see table 2 column 1.

The sprouting rate clearly increases with decreasing bulb weight. The equation and the line were made only on the basis of the strains grown together in the same field, see material and methods. They are numbered 1 - 8 in figure 17 and column 1 of table 2.

As the bulb size, among other things, depends on the spacing in the field and this again depends on the germination capacity of the lot of onion seeds in question, it is impossible in this case to ascertain that the average bulb weight is characteristic of the different strains.

A corresponding connection could not be detected in the 1967/68 experiment probably because of the above-mentioned bad conditions which too strongly affected the physiology, the susceptibility to rot, and the sprouting rate.

No connection between the bulb weight and the percentage of rot could be proved.

3.4. Taste

This matter was only examined in the 1965/66 experiment. Cooked onions were used (cf. Truelsen 1960), and several colleagues acted as judges. The results were as in Truelsen (1960). Under the conditions in question, no appreciable differences were pointed out by use of doses up to 250 krads, see table 1. If differences do exist, they are so small that they can only be determined with certainty by a panel of experts. To get an exhaustive answer it would be necessary also to taste the raw onions.

4. DISCUSSION

From the literature review it is evident that small doses used at the right time have an excellent sprout-inhibiting ability, and that higher doses may give more sprouting. When the presented results are considered as a whole, the 6 krad dose stands out as the best. There are several reasons for that. Generally the incidence of rot was less after this dose than after the others, leaving the control out of account, even though deviations do occur. In all experiments 6 krads exhibited the smallest amount of sprouting, which then increases with the dose for 12 and 25 krads. At least as interesting is the phenomenon of transitory stimulation of the sprouting which according to the literature, see above, was most often observed after application of higher doses. After 6 krads it did not occur at all, after 12 krads it occurred only after the wet autumn of 1967/68 especially in the experiment with strains of cultivars where the transitory stimulation of the sprouting was very pronounced in some of the strains, see figure 16. After 25 krads this effect occurred both in the "good" year of 1966/67 and in the "bad" year of 1967/68, cf. the text above, but not in the experiments of 1968/69 where the onions were dried immediately after lifting and irradiated a fortnight earlier than the preceding years. These facts indicate that a mechanism, most likely the physiology of rest and dormancy, affected to give this transitory stimulation of sprouting, is a very sensitive one, not only to irradiation, but also to the environmental conditions and to the treatments after harvest. The later fading-off of the sprouting rate is not surprising because of the serious disturbance of the physiology and the metabolism of the nucleic acids, cf. the literature review, but one can hardly believe that a greater part of the sprouting should be a cell extension (hypertrophied cells) rather than real growth, cf. Metlitskii et al. (1964).

From the earliest experiments with irradiation of onions for extension of their storage lives few strains have often been used. They clearly show that essential differences exist. More extensive are the presented experiments with strains of cultivars. From them it may in addition be seen how important it is to use strains with good storability not only as regards sprouting, but to a high degree also as regards tolerance against storage rot.

The variation in storage rot, as observed in the present work and known from the literature reviewed, may have several causes. It depends naturally on the pre-history of the stored onions during which microorganisms (amount and species) were inocculated on them and during which attacks - though invisible - already have been established as was for example the case with the 1967/68 experiments. Besides differences in radioresistance of the microorganisms the number of their cells present plays an important role and is probably the main reason for the higher resistance in established attacks (cf. Coney and Bramley 1965). No work has been done on the radioresistance of Botrytis allii, but on the basis of the above and the statements on related organisms (cf. e.g. Beraha, Smith and Wright 1960, Barkai-Golan, Temkin-Gorodeiski and Kahan 1967) one can hardly believe it possible to reach the conclusion that it should be possible to destroy B. allii without damaging the onions as alleged by Staden (1966), and it is surprising, too, that some authors have found a decrease in storage rot after small doses. It is more easily understandable that higher doses may lead to severe microbial attacks because the damage to the tissues becomes very serious at the same time as the dose is still far from sterilizing the products (cf. e.g. Beraha, Smith and Wright 1960). The presented results show that even a dose of 6-12 krads may lead to increased storage rot - mainly caused by B. allii - if the material is incorrectly handled. Therefore, in this author's opinion the results make it safe to presume that the irradiated bulbs are more susceptible to attacks than the non-irradiated ones.

Other things being equal it must be regarded as absolutely necessary for studying the effect of the bulb size that the bulbs are well ripe and in a good physiological condition. Therefore it is not surprising that it has been possible only in the experiment with strains of cultivars in 1966/67 to get a clear picture of this effect. If it is true that the larger onions rot faster than the smaller ones (cf. the literature review), the effect of less sprouting may be obscured when measured as storability at non-optimal conditions. This is possibly also the case when the physiology is affected, see table 3 and the corresponding text.

5. GENERAL CONCLUSIONS

Based on the literature reviewed and on the results presented the following general conclusions are drawn:

1. To obtain a good result it is necessary that the onions are grown at the best possible conditions to ensure uniform maturation. The lifting must be carried out as soon as the onions are mature for harvest. They must then be dried, preferably artificially, as besides giving a good scale colour this reduces the growth conditions for the pathogens. (Based on results presented in agreement with the literature).

2. Only first-class market onions are usable for irradiation because even apparently negligible deviation from that category will increase the rot during storage. The reason is that irradiated onions are generally more susceptible to rot than non-irradiated ones. (Based on results presented).

3. It is very important to use strains of cultivars with specially good storability, i. e. late sprouting and tolerance against storage rot, as to which they differ greatly. The strains used in common practice had the best or were among those with the best storability of the strains investigated (cf. the results). Allium cepa L. has been used in the greater part of the investigations throughout the world, but the results with other species, A. sativum L. (garlic) and A. ascolonicum L. (shallots), fall within the differences between the strains of cultivars of onions. (Based on literature and on results presented).

4. The radiation used must have energy enough to penetrate to the growth centre, and the dose rate must be high enough to reach the dose needed in a reasonably short time. The irradiation should be applied when the onions are in the deepest state of rest, i. e. about a fortnight after harvest. Used at that time the dose needed for sprout inhibition is smallest. In the results presented it is 6 krads, but at other conditions and with other strains of cultivars it may vary a little to both sides. With irradiation at a later time higher doses are needed to inhibit the sprouting, but such doses may have an adverse effect by intensifying the storage rot. (Based on literature and on result presented).

5. The state of rest and dormancy is essential for obtaining good results. It is affected by environmental conditions and handling about the harvest time, and it is sensitive to irradiation, especially after the effect brought about by the conditions mentioned. This may lead to a transitory stimulation of the sprouting which may be observed at low (12 krads) as well as at high doses, possibly dependent on the deepness of the rest. At irradiation when dormancy passes into sprouting it is impossible to inhibit the sprouting with doses that do not disturb the quality of the onions.

   The lowest dose necessary for sprout inhibition will give the greatest amount of first-class market onions during storage because it does not affect the incidence of rot. (Mainly based on results presented).

6. Storing of the onions close to the freezing point may awake them from their rest and promote an earlier initiation of sprouting, while temperatures about 13-17^{o}C give more sprouting during storage than do both higher and lower temperatures. The best storage temperature is probably about 5^{o}C. High as well as low relative humidity have a deleterious effect on storability. 80-95% r. h. is probably the optimal moisture content for well-handled onions. (Based on literature mainly).

7. At the above conditions (1-6) irradiation will have little effect on the incidence of rot, but all deviations from them may result in an increase in both sprouting and rot. Doses above the optimal for sprout inhibition cause an increase in storage rot and may promote sprouting, see above. Small onions sprout faster than larger ones, on the other hand there are few indications of more rot in the larger ones. It is easier to stop root sprouting than top sprouting. (Based mainly on the results presented).

8. Based on the whole storage period the non-irradiated onions lose more by respiration and transpiration than do the irradiated, but measured from time to time during storage the loss is greatest for the irradiated onions in the first months of storage until the sprouting accelerates in the control. (Based both on literature and on results presented).

9. Irradiation may often cause a brownish discoloration of the growth centre, but with great variation between strains of cultivars and from one bulb to another. The cause is not elucidated though it seems that adverse conditions promote it. Some authors are of the opinion that it is due to dying and drying out of the growth centre after some growth, while others state that it is merely a pre-existing tendency which may be intensified by irradiation because the discoloration may also be found in non-irradiated onions. The general impression is that this discoloration does not make the onions objectionable for most kinds of use. (Based exclusively on literature).

10. The culinary value is almost unchanged or rather improved to a small extent by a sweeter and less pungent taste. The amounts of carbohydrates and vitamin C are unchanged by sprout inhibiting doses. It is noted that the wholesomeness is not affected by the doses tried, i. e. up to 100 krads. (Based on literature mainly).

11. All considered, only onions to be sold in spring and summer can be advantageously irradiated. At this time the advantage of irradiation is great as in June-July 50-60% or more of the original amount is still available for the market, whereas only 10-25% or less of the control are left at that time. (Based exclusively on results presented).

ACKNOWLEDGEMENTS

The author wishes to thank K. Iversen, agricultural advisor to the Danish Onion Growers' Union, and his assistants for valuable technical assistance and K. V. Andersen's factory for storing the onions at Stevns.

REFERENCES

Barkai-Golan, R., N. Temkin-Gorodeiski and R.S. Kahan, Effect of gamma irradiation on development of fungi, Botrytis cinerea and Rhizopus nigricans, causing rot in strawberry fruits. Food Irradiat. 8, 34-36 (1967).

Beraha, L., M.A. Smith and W.R. Wright, Gamma radiation dose response of some decay pathogens. Phytopatholoty 50, 474-476 (1960).

Blinc, M., Storage of γ-irradiated potatoes and onions. Bul. Sci. Cons. Acad. R.P.F. Yougoslavie 4, 102 (1959).

Boswell, V.R., Influence of the time of maturity of onions upon the rest period, dormancy, and responses to various stimuli designed to break the rest period. Proc. Amer. Soc. Hort. Sci. 1923, 225-233 (1924a).

Boswell, V.R., Influence of the time of maturity of onions on the behaviour during storage, and the effect of storage temperature on subsequent vegetation and reproductive development. Ibid. 1923, 234-239 (1924b).

Brunelet, L. and P. Vidal, inhibition de la montée en végétation des bulbes alimentaires. Revue de la Conserve, Mars-Avril, 1960, 3-11 (1960).

Campos, F.F., W.M. Generoso and J.M. Capinpin, Effects of X-rays on the bulbs and seeds of onions (Allium cepa L.). Philipp. Agr. 44, 125-133 (1960).

Coney, H.M., and W.J. Bramlage, Effect of sporepopulation and age of infection on the response of Botrytis cinerea to gamma radiation. Phytopathology 55, (2), 1013-1015 (1965).

Dallyn, S.L., and R.L. Sawyer, Effect of gamma and fast electron irradiation on storage qualities of onions. Proc. Amer. Soc. Hort. Sci. 73, 390-397 (1959a).

Dallyn, S.L., and R.L. Sawyer, Effect of sprout inhibiting levels of gamma irradiation on the quality of onions. Ibid. 73, 398-406 (1959b).

Dallyn, S.L., R.L. Sawyer and A.H. Sparrow, Extending onion storage life by gamma irradiation. Nucleonics 13, 48-49 (1955).

Dharkar, S.D., Report on Barc programmes in food irradiation: status of project on preservation of potatoes and onions by sprout inhibition. Food Irradiation. Proceedings of a Seminar, Trombay, 13-14 January 1969, 24-27, (Bhabha Atomic Research Centre, Trombay, Bombay 1969).

Hegnauer, R., Chemotaxonomie der Pflanzen 2, IV, Allioideae, 315-325 (Birkhauser, Basel, 1963).

Hellmers, E., Botrytis on Allium species in Denmark. Botrytis allii Munn and B. globosa Raabe. Contr. Dept. Plant. Pathol. Roy. Veter. Agric. Coll. Copenhagen, 25: 1-51 (1943).

Hennebert, G. L., Les Botrytis des Allium. Meded. Landb. Hogesch. Opzoek. Stns., Gent 28 (2), 851-876 (1963).

Hluchovský, B. and V. Srb, Veränderungen der Zellpermeabilität bei Allium cepa L. nach Röntgenbestrahlung. Biol. Zentralbl. 82, 73-94 (1963).

Hori, S., T. Kawasaki and S. Kitoh. Gamma irradiation of onion bulbs to inhibit sprouting. II. Browning phenomenon in inner buds of irradiated onion bulbs, and a method of early detection for inhibition of sprouting. Ann. Rept. Radiat. Center Osaka Pref., Japan 5, 90-92 (1964). Quoted from NSA 19, 32627 (1965).

Jones, H. A., Preliminary report on onion dormancy studies. Proc. Amer. Soc. Hort. Sci. 1920, 128-133 (1921).

Kahan, R. S., and R. Padova, Sprouting control of stored garlic. Progress Report for 1966 on Uses of Radioisotopes and Irradiation of Agricultural Products. (Industrial Applications Department, IAEC, Soreq Nuclear Research Centre, Yavne, Israel), 16-17 (1966).

Kahan, R. S. et al., Radiation control of sprouting in stored onions. Ibid. 15-16, (1966).

Kahan, R. S. and N. Temkin-Gorodeiski, Storage tests and sprouting control on Up-to-date variety potatoes and on an experimental onion variety (Beit-alpha). Preservation of Fruit and Vegetables by Radiation. Proceedings of a Panel, Vienna, 1-5 August 1966, 29-37, (IAEA, Vienna, 1968).

Kepka, A. K., The influence of some factors on the keeping quality of onions. Acta Horticulturae (Proc. Symp. Vegetabl. Storage Intern. Soc. Hort. Sci., Norway, Aug. 11-14, 1969). In print.

Knobaluch, F., Tørringsforsøg med skalotteløg. Tidsskr. Planteavl 62, 677-692 (1959).

Knoblauch, F., Kombineret køle og varmepræparering af skalotteløg til læggebrug. Ibid. 70, 22-33 (1967).

van Kooy, J. G. and D. J. Langerak, Irradiation of onions. Food Irrad. 2, (1), A6-A7 (1961).

Korableva, N. P. and L. V. Metlitskii, Effect of gamma-irradiation on the growth and nucleic acid content of onions. Dokl. Biol. Sci. Sect. USSR 150, 598-600 (1963).

Kurki, L. M., Moisture in vegetable storage. Acta Horticulturae (Proc. Symp. Vegetabl. Storage. Intern. Soc. Hort. Sci., Norway, Aug. 11-14, 1969). In print.

Lewis, N. F., and P. B. Mathur, Extension of storage lives of potatoes and onions by cobalt-60 γ-rays. Intern. J. Appl. Radiat. Isot. 14, 447-453 (1963).

McQueen, K. F., Sprout inhibition of vegetables using gamma radiation. Radiation Preservation of Foods. Proceedings of an International Conference, Boston, Mass., 27-30 September 1964, 127-140 (National Academy of Sciences, National Research Council, Washington, D. C., 1965). (NAS-NRC-Publication, 1273).

Mann, L. K., and D. A. Lewis, Rest and dormancy in garlic. Hilgardia 26, 161-189 (1957).

Mathur, P. B., Extension of storage life of garlic bulbs by γ-irradiation. Intern. J. Appl. Radiat. Isot. 14, 625 (1963).

Meshitsuka, G. et al. Sprout inhibition of onion bulbs by γ-rays. Tokyo Metropol. Isot. Center Ann. Rept. 1, 78-81 (1962). Quoted from NSA 17, 36098 (1963).

Messiaen, C. M., P. Pereau-Leroy and J.-P. Leroux, Amélioration de la conservation des bulbes d'ail par irradiation gamma. C. r. hebd. Seanc. Acad. Agric. Fr. 1969 (16 Avril), 485-490 (1969).

Metlitskii, L. V. et al., Rest-period-controlled use of ionizing radiation during storage of onions and garlic. Biokhim. Plodov. i Ovoshehei, Akad. Nauk USSR Inst. Biokhim, 163-190 (1964). Transl. DTC 209, 1971.

Mullins, W. R. and H. K. Burr, Treatment of onions with gamma rays: Effect of delay between harvest and irradiation. Food Technol. 15, 178-179 (1961).

Mumtaz, A. et al., Inhibition of sprouting in onions by gamma radiations. Food Irradiat. 10, 10-14 (1970).

Nuttall, V. W., L. H. Lyall and K. F. McQueen, Some effects of gamma radiation on stored onions. Can. J. Plant. Sci. 41, 805-813 (1961).

Ojima, T. et al., Gamma irradiation of onion bulbs to inhibit sprouting. Ann. Rept. Radiat. Center Osaka Pref. 4, 112-114 (1963). Quoted from NSA 18, 23255 (1964).

Ottosson, L., Problems to store different vegetables together. Acta Horticulturae (Proc. Symp. Vegetabl. Storage, Intern. Soc. Hort. Sci. Norway Aug. 11-14, 1969). In print.

Patil, J. A., Gamma irradiation for vegetable storage A-onion bulbs. Agric. Magaz., Parabhani 7, 3-11 (1965/66).

Røed, H., Botrytis (gray mold) on Allium cepa and Allium ascalonicum in Norway. Acta Agric. Scand. 1, 20-39 (1952).

Sawyer, R. L. and S. L. Dallyn, Vaporised chemical inhibitors and irradiation, two new methods of sprout control for tuber and bulb crops. Proc. Amer. Soc. Hort. Sci. 67, 514-521 (1956).

Shirokov, E. P., Research on the storage of cabbage, carrots and onions in the USSR. Acta Horticulturae (Proc. Symp. Vegetabl. Storage, Intern. Soc. Hort. Sci., Norway Aug. 11-14, 1969). In print.

Skou, J. P., Changes in the permeability of carrot tissues due to γ-irradiation and other physical and chemical treatments. Physiol. Plant. 16, 423-441 (1963).

Skou, J. P., On radiation-induced sprout inhibition and the by-effects. Kerntechnik 8, 510-513 (1966).

Skou, J. P., Consumer surveys in Greenland for acceptance evaluation during storage of potatoes sprout-inhibited with γ-rays or Fusarex. Risö Report No. 163, 30 pp. (1967).

Skou, J. P., Effects of calcium on storage rot in irradiated and non-irradiated carrots. Acta Horticulturae (Proc. Symp. Vegetabl. Storage, Intern. Soc. Hort. Sci., Norway, Aug. 11-14, 1969). In print.

Skou, J. P., and J. B. Henriksen, Increased susceptibility to storage rot in potatoes and carrots after sprout inhibiting gamma irradiation. Radiation Preservation of Foodstuffs. Sec. Scand. Meet. Food Preserv. Stockholm, 1963. IVA Medd. 138, 48-54 (1964).

Solanas, J., and A. Darder, Preservation of Venezuelan vegetables by irradiation. Food Irradiat. 5, A13-A21 (1964).

Srb, V., Immediate and short-term changes in cell permeability after X-irradiation. Radiat. Res. 21, 308-313 (1964).

Srb, V., Irreversible effects of ionizing RTG-radiation on the osmotic properties of the epidermal cells of Allium cepa L. bulbs. Biol. Plant., Praha 7, 270-284 (1965a).

Srb, V., Učinek rtg záření na skladovatelnost sazečky cibule kuchynské (Allium cepa L.). Eng. sum., The effect of X-ray irradiation on the storage of seedlings of kitchen onion (Allium cepa L.). Genet. a Slech., Praha 1, 65-79 (1965b).

Staden, O. L., Koelen en bestralen van groenten en fruit. Conserva, The Hague, 15, 154-155 (1966/67).

Sørensen, H., Sortsforsøg med kepaløg (rødløg) 1935-38. Tidsskr. Planteavl 45, 84-96 (1941).

Truelsen, T. A., Irradiation of potatoes, onions and carrots to inhibit sprouting. Risö Report No. 16, 67-68 (1960).

Truelsen, T. A., Irradiation of potatoes. Effects on sugar content, blackening, and growth substances. Radiation Preservation of Foodstuffs, Sec. Scand. Meet. Food Preserv., Stockholm, 1963. IVA Medd. 138, 55-62 (1964).

Umeda, K., H. Takano and T. Sato, Sprout inhibition of onions by ionizing radiation. Part 1. Effect of delay between harvest and irradiation on sprouting of var. sapporoki and senshuki. Shokuryo Kenkyujo Kenkyu Hokoku, 25, 24-31 (1970). Quoted from NSA 24, 24899 (1970).

Vegis, A.: Ruhezustände bei höheren Pflanzen, Induktion, Verlauf und Beendigung: Übersicht, Terminologie, allgemeine Probleme. In W. Ruhland (ed.), Encycl. Plant Physiol. 15, (2), 499-533 (1965).

Wanscher, J. H., A study of the relation between the taxon and the stock, and its bearing on the principles of the "International Code of Nomenclature for Cultivated Plants 1961". Royal. Vet. and Agric. Univ., Copenhagen. Yearbook 1964, 190-208 (1964).

Wanscher, J. H., Philosophical considerations on the abstract and concrete in nomenclature conceptions. Thesis, Royal Vet. and Agric. Univ. 1971 (De studerendes råds forlag, Copenhagen 1971).

Watanabe, T., and H. Tozaki, The Co-60 irradiation of garlic to prevent sprouting and its influence to alliin-lyase activities. Food Irradiat., Japan 2, 106-112 (1967). Abstr. and 10 tables in English.

Zidan, E. A., Extending the storage life of Egyptian onions by gamma radiation. Alexandria J. Agr. Res. 15, 59-71 (1967).